



AURORA ON GANYMEDE

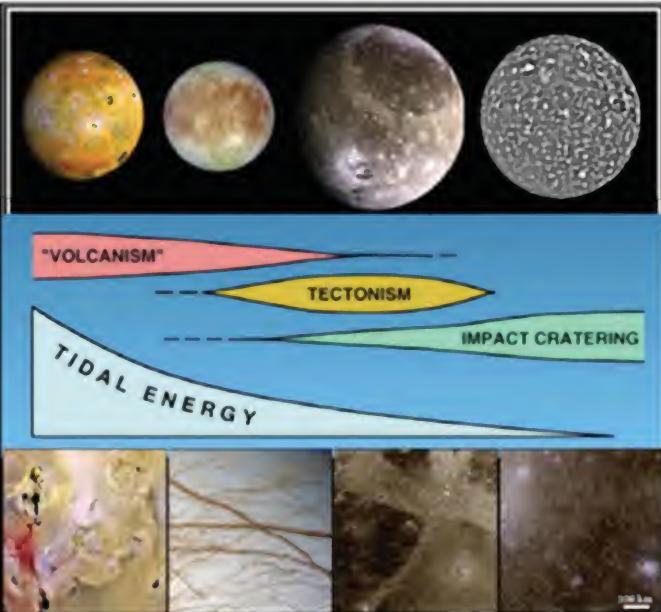
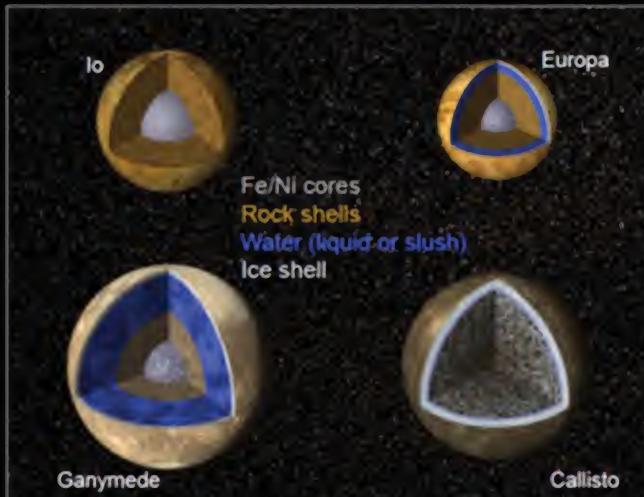
Melissa A. McGrath
NASA Marshall Space Flight Center

Ganymede

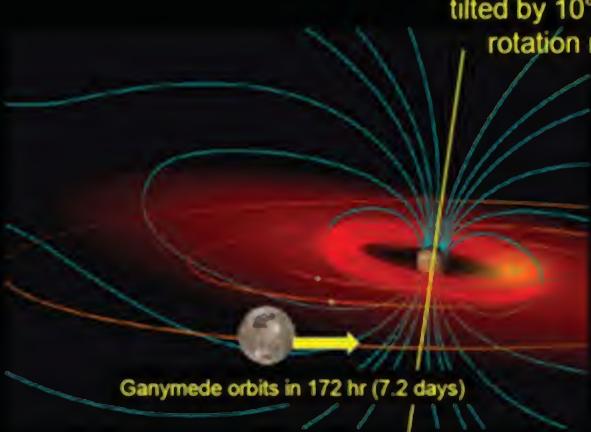


The largest satellite in the solar system, larger than Mercury and Pluto, only slightly smaller than Mars

Interior structures greatly clarified by Galileo close flybys



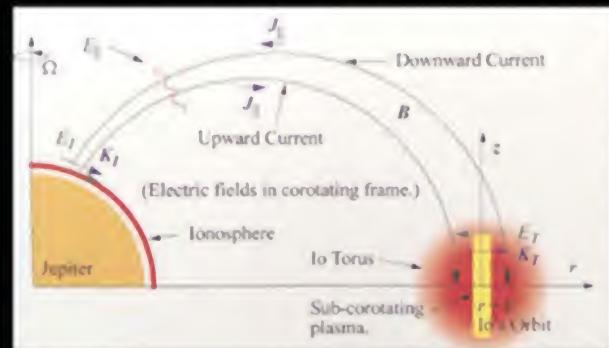
magnetic field:
tilted by 10°, 10 hr
rotation rate



All the Galilean satellites have tenuous atmospheres and associated ionospheres that exhibit a wide range of properties, including surface pressures ranging from picobar (Europa, Ganymede) to nanobar (Io).

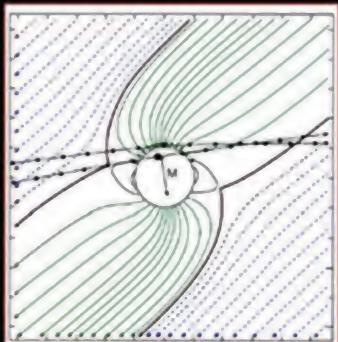
	Io	Europa	Ganymede	Callisto
Primary constituent	SO ₂	O ₂	O ₂	O ₂
P ₀ (nbar)	0.6	7x10 ⁻⁴	7x10 ⁻⁴	0.01-0.1
N (cm ⁻²)	2x10 ¹⁶	5x10 ¹⁴	5x10 ¹⁴	~ 10 ¹⁶ O ₂ 8x10 ¹⁴ CO ₂
Source	Volcanoes/ sublimation	Sputtering/ sublimation	Sputtering	Sputtering/ meteorites?

Satellites with atmospheres and ionospheres immersed in the strong magnetic field and plasma environment of the Jovian magnetosphere produce a strong electrodynamic interaction between plasma and satellite



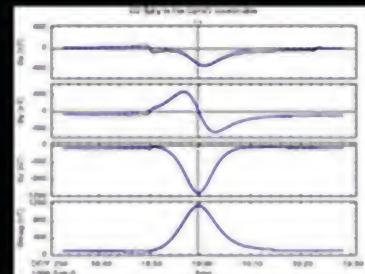
The Galilean satellites are unique because emissions from their atmospheres, produced by this interaction, have been imaged. Each has distinctive auroral emissions that provide a unique signature of the plasma interaction at the satellite.

Galileo discovery of Ganymede magnetic field



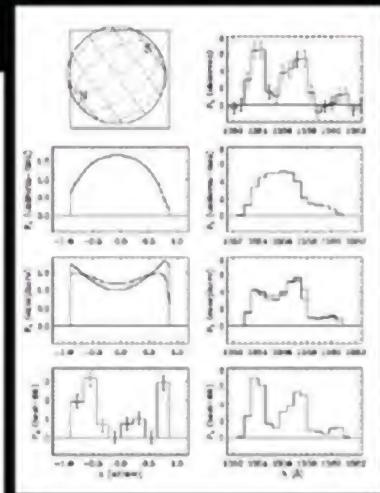
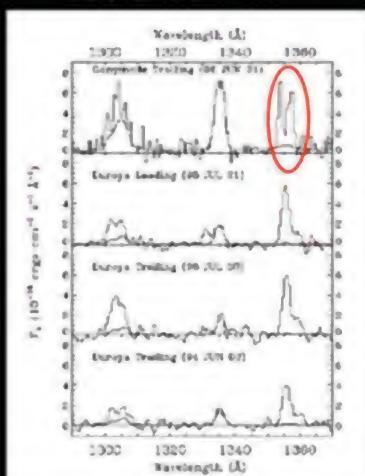
Gurnett et al. 1996
Kivelson et al. 1996

Strong magnetic field and considerable field rotation near Ganymede indicated the perturbations were Ganymede-associated.

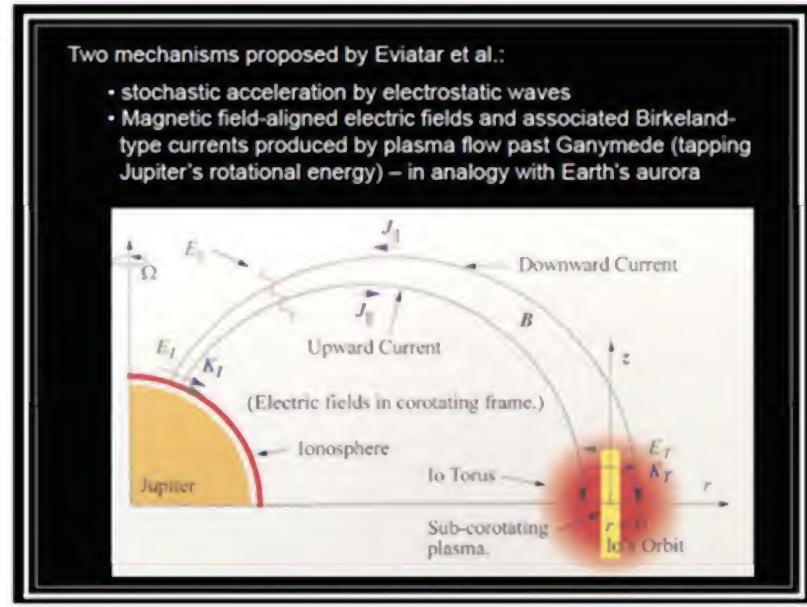
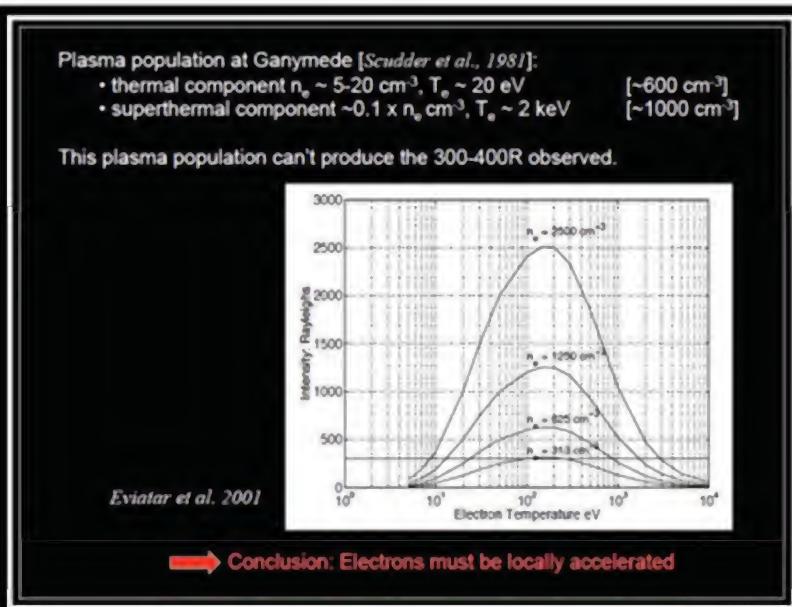
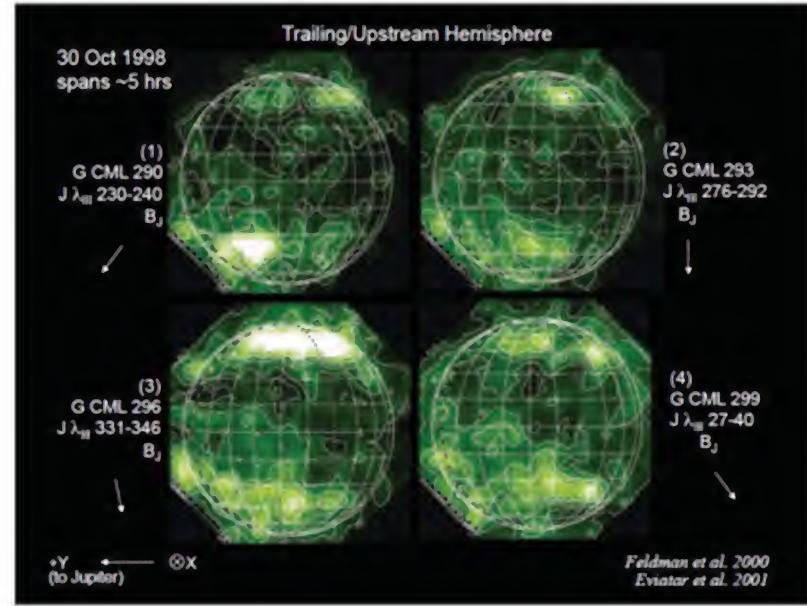
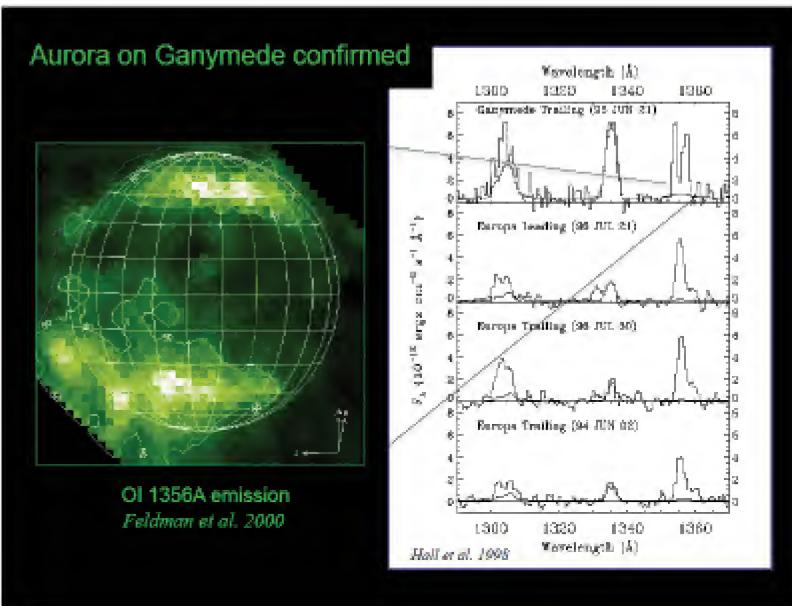


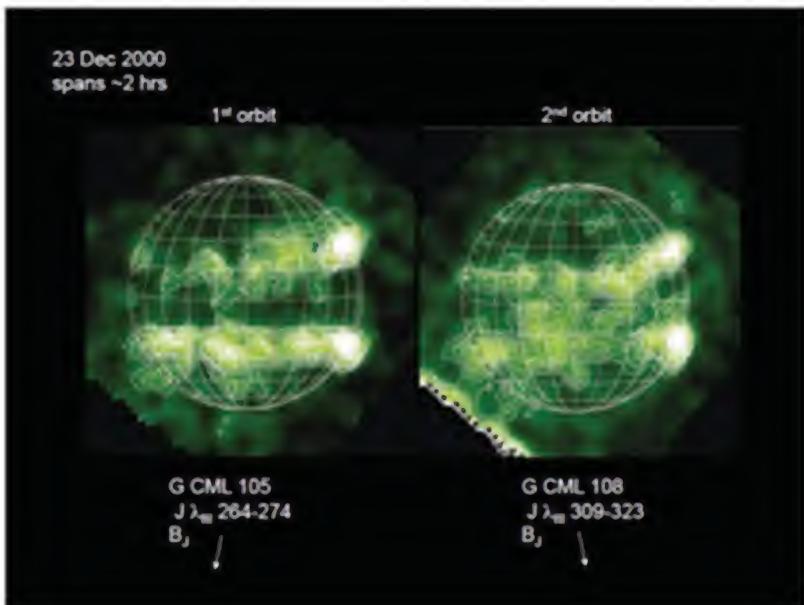
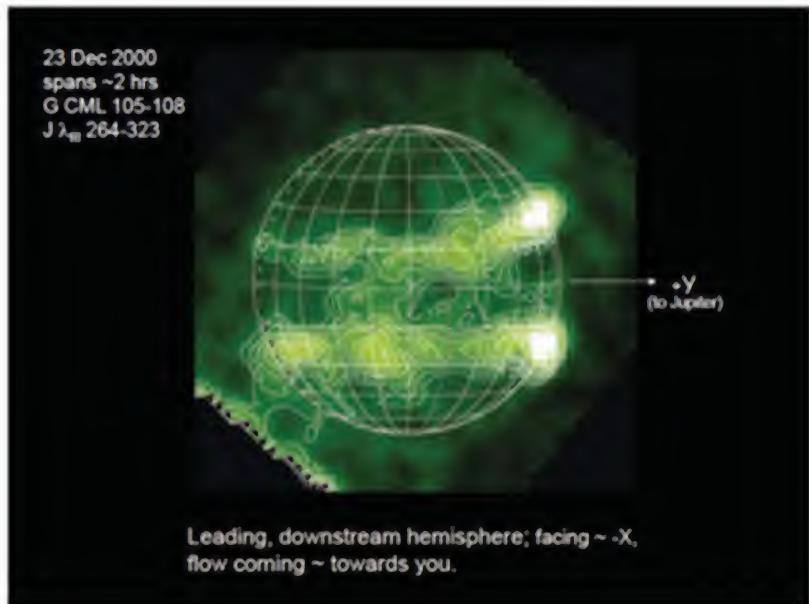
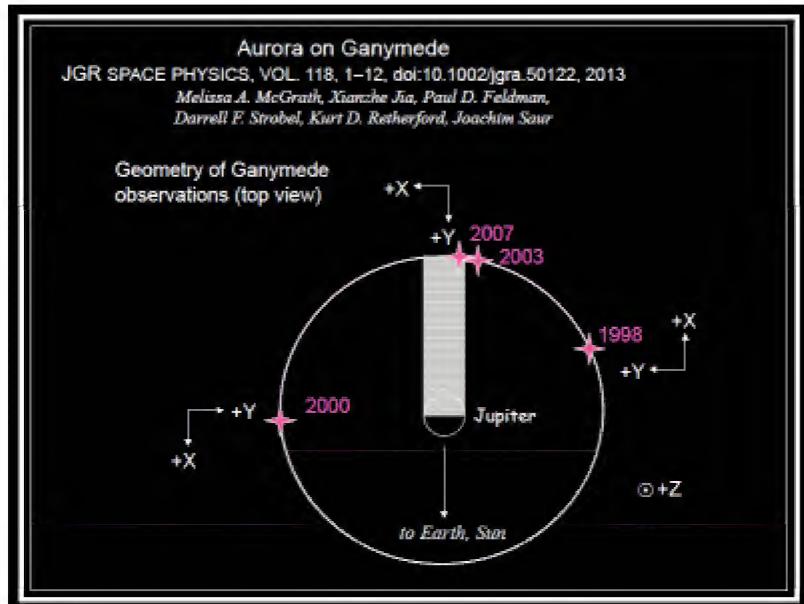
Detection of O₂ atmosphere

Hall et al. 1998



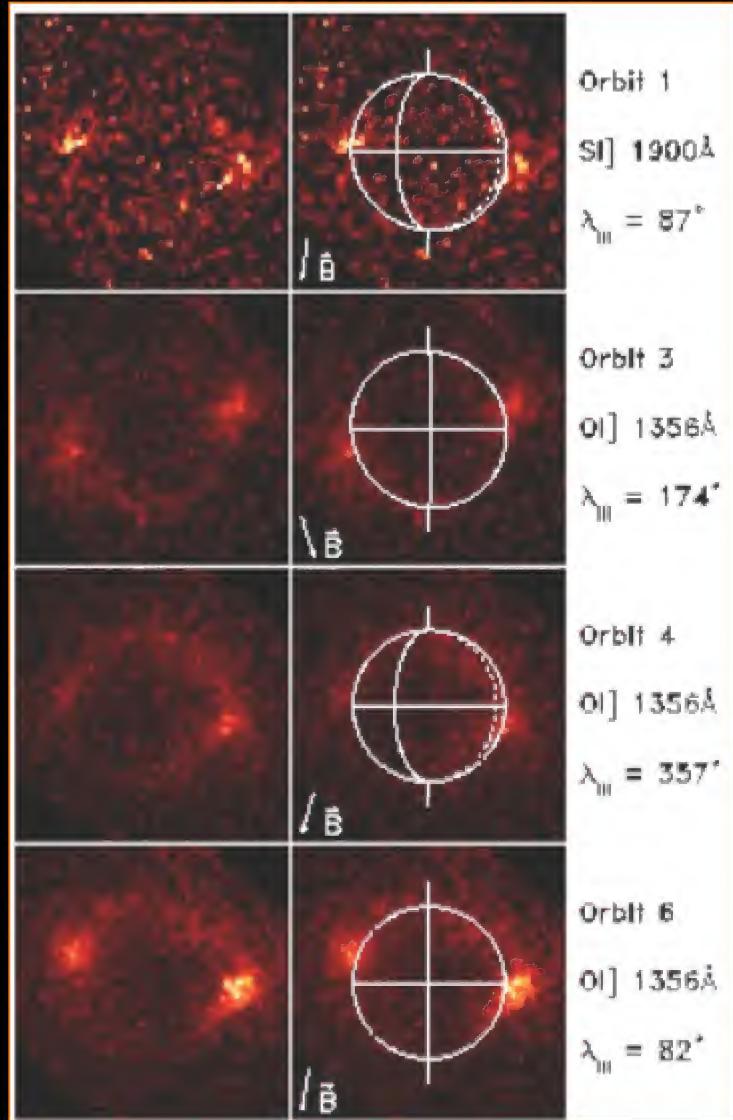
Aurora on Ganymede?

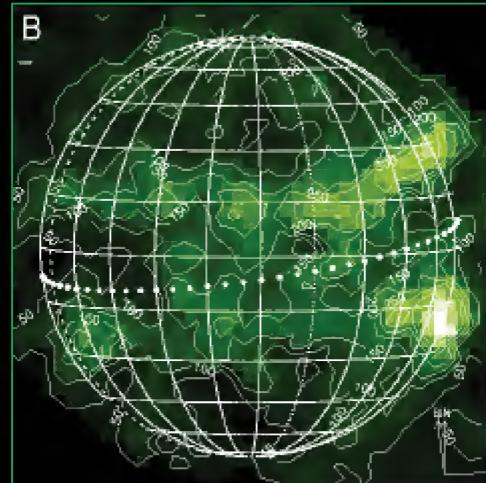
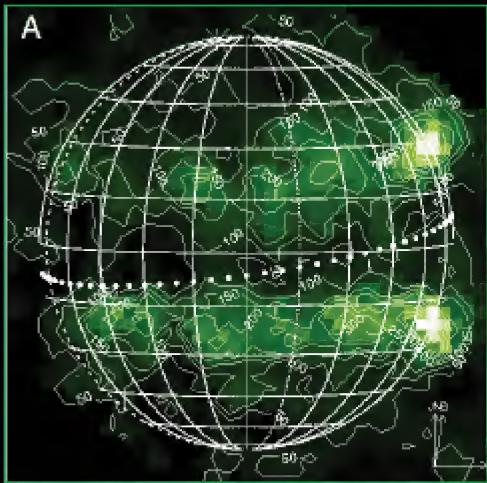




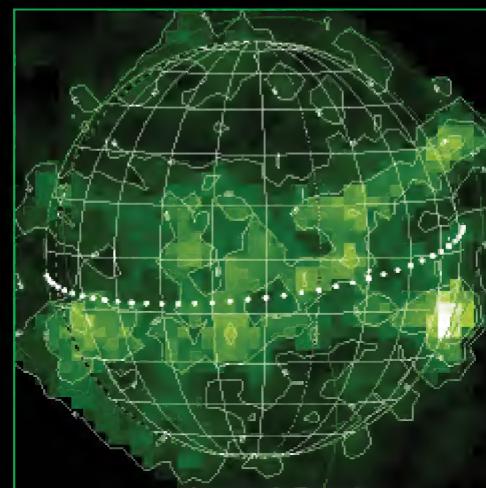
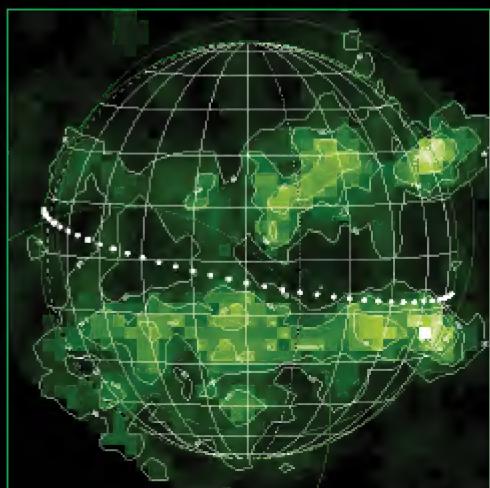
At Io, the auroral emission has a very different morphology: equatorial bright spots that rock with changing Jupiter B field orientation

Roesler et al. 1999





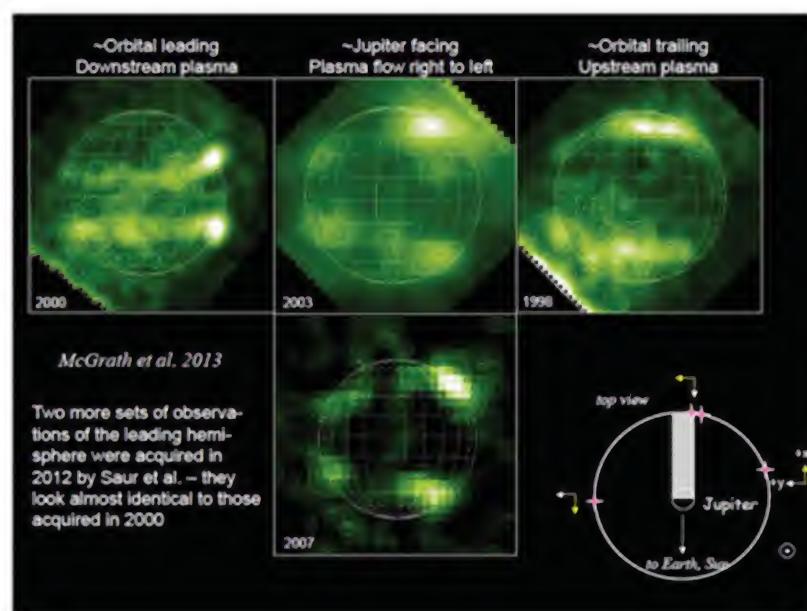
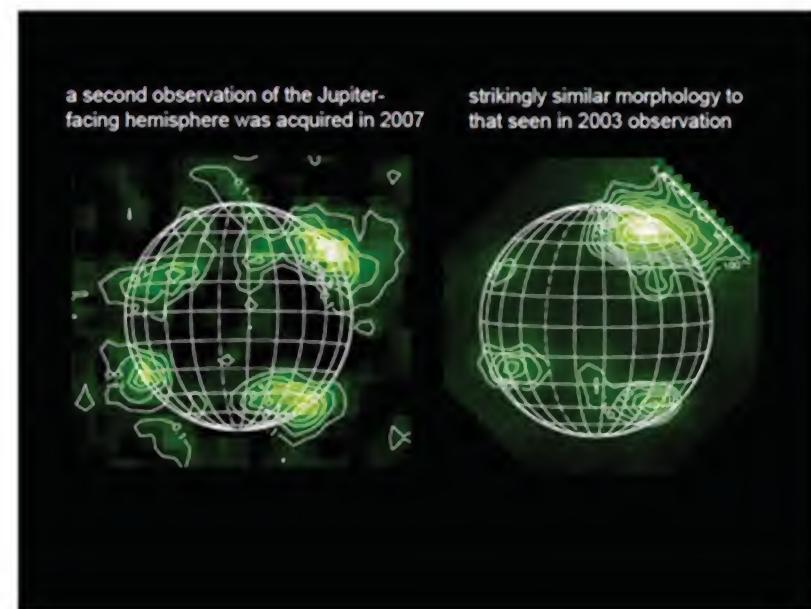
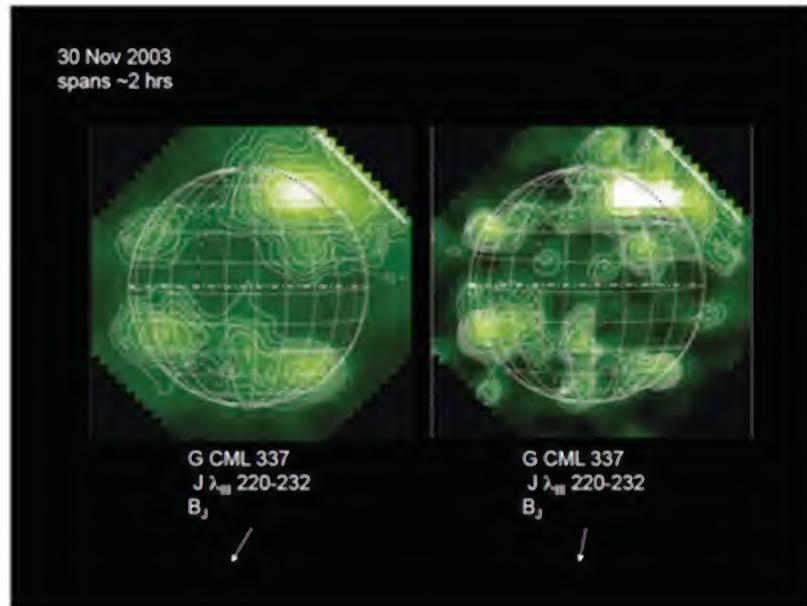
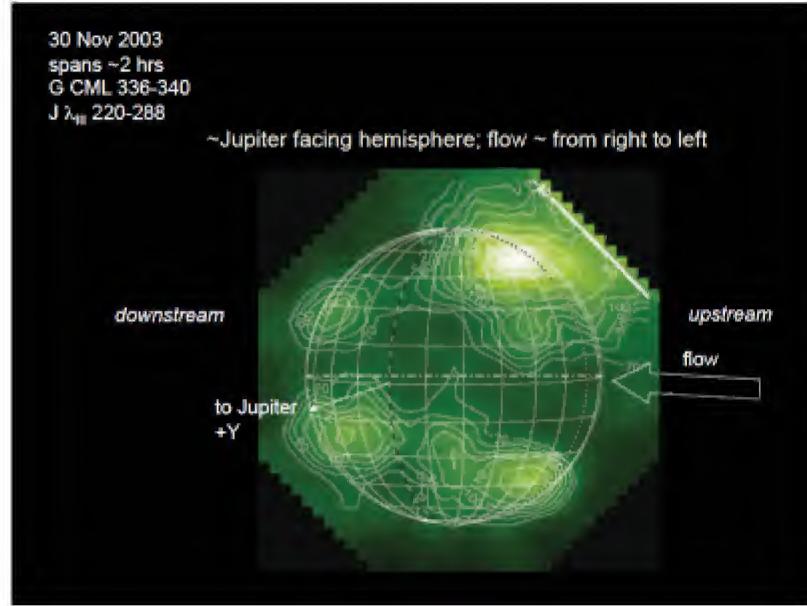
Ganymede B field
equator superposed

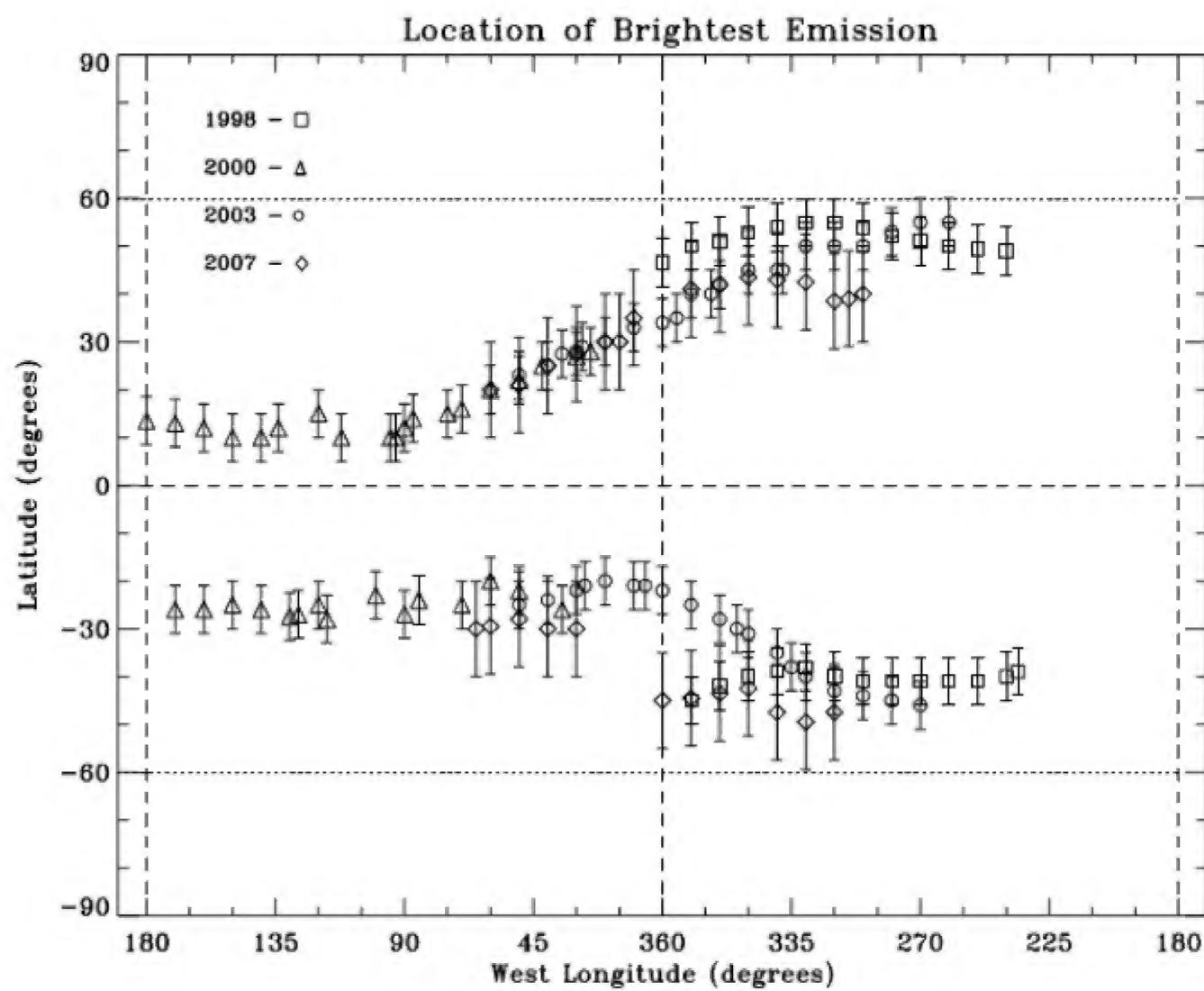


Jupiter B field
equator superposed



Conclusion: Ganymede's auroral oval does not rock like Io's spots

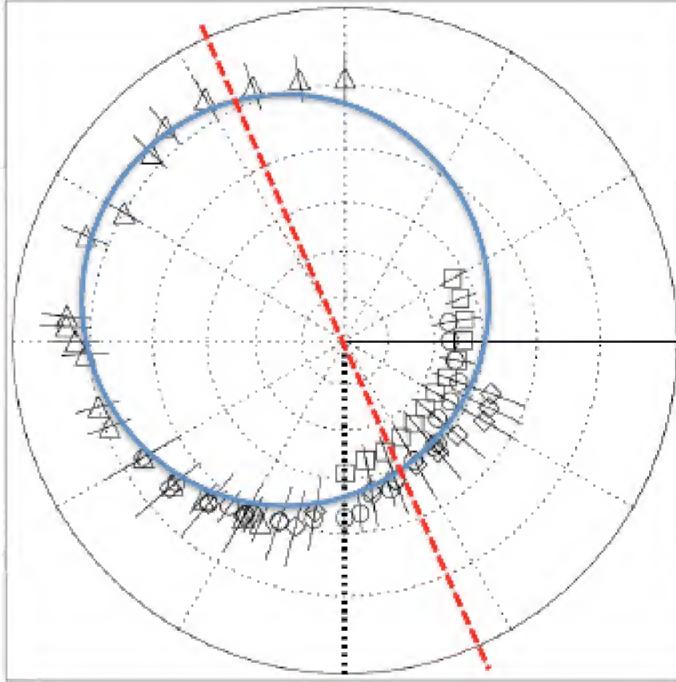
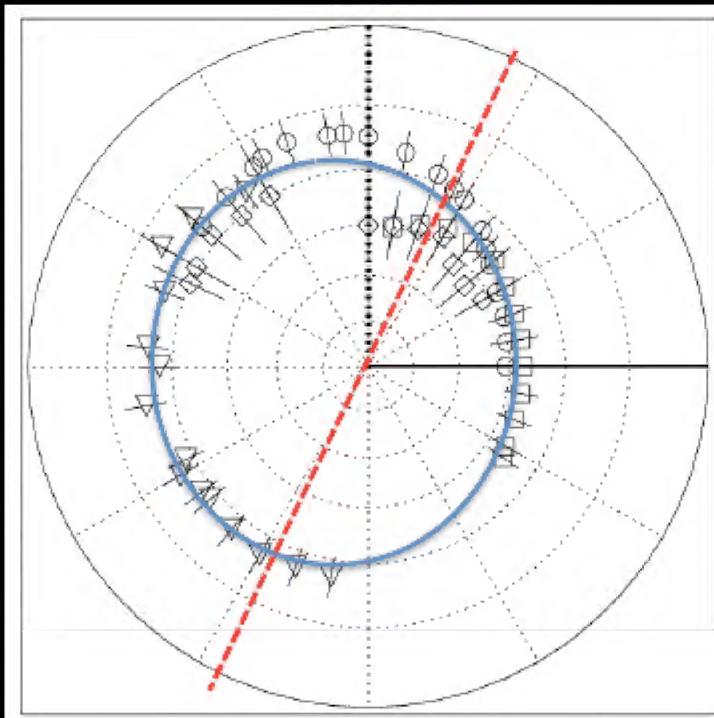




North pole projection

← plasma flow

to Jupiter



Ganymede magnetic pole:
156°W, 86°N
336°W, 86°S

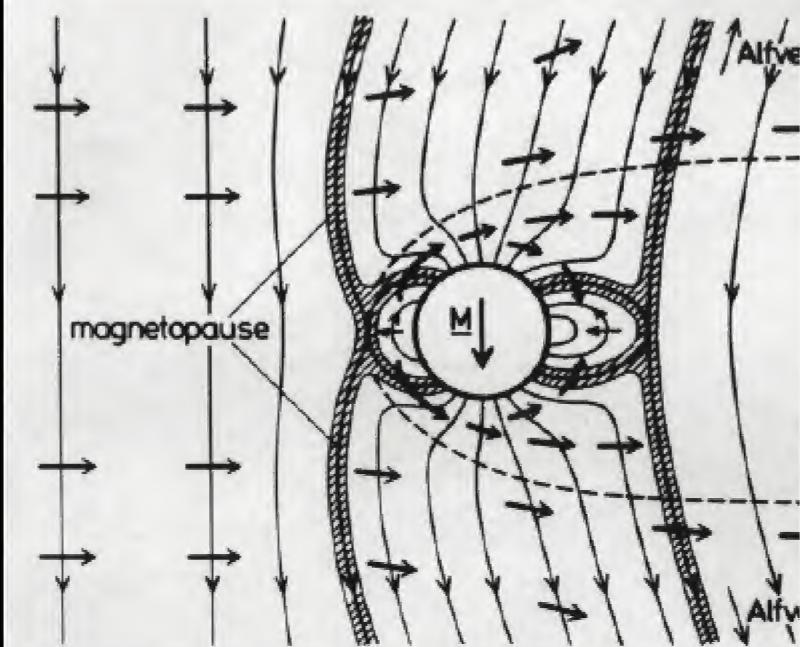
South pole projection

Summary of observed characteristics

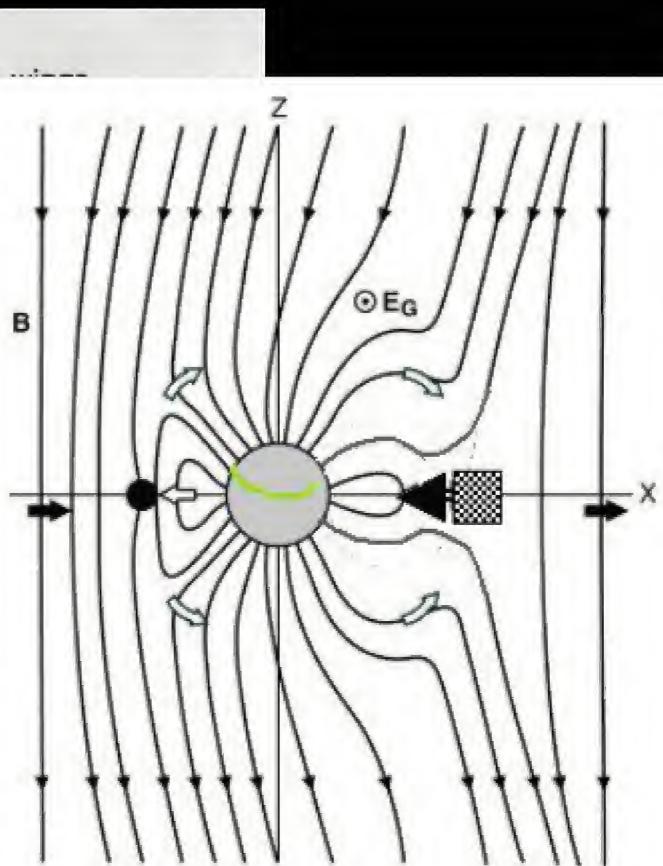
- The overall emission pattern is relatively stable with time.
- In the downstream hemisphere, the emission extends to significantly lower latitude in the northern hemisphere than the southern hemisphere.
- The opposite is true in the upstream hemisphere: emission is at higher latitude in the northern hemisphere than the southern hemisphere.
- The emission is not symmetric about either pole.
- The emission is not symmetric about the equator.
- The auroral oval is stretched in the downstream direction, more so in the N than the S.
- The auroral oval is not symmetric about the plasma flow direction. It appears to be roughly aligned with Ganymede's magnetic axis, especially in the north.
- Emission is always brightest near the NW (dusk) limb, followed by SW limb, then SE limb, then NE limb

Comparison with Models

- One proposed mechanism: Electrons accelerated by field aligned potentials at the boundary between Ganymede's open and closed field magnetic lines produce the auroral emission
- I will show you comparison between location of the open-closed field line boundary (OCFB) and the location of the auroral emission for several different models:
 - Khurana et al. (2007): vacuum superposition of Ganymede & Jupiter magnetic fields
 - Koop & Ip (2002): resistive MHD model
 - Jia et al. (2008, 2009): global 3-d single-fluid MHD model
- For all comparisons I will show models where Ganymede is ABOVE (in red), IN (in green), and BELOW (in blue) the plasma sheet



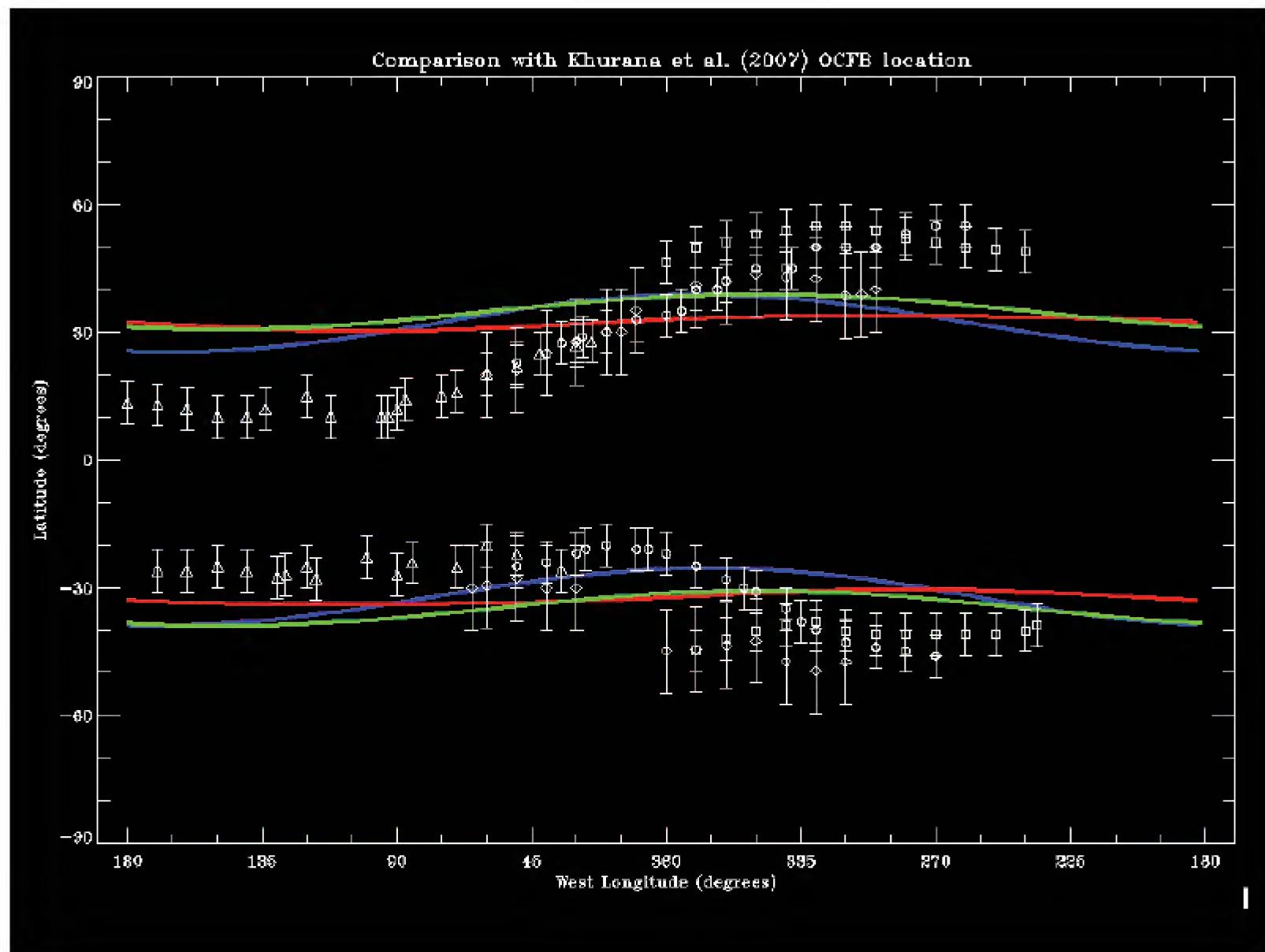
Neubauer 1998

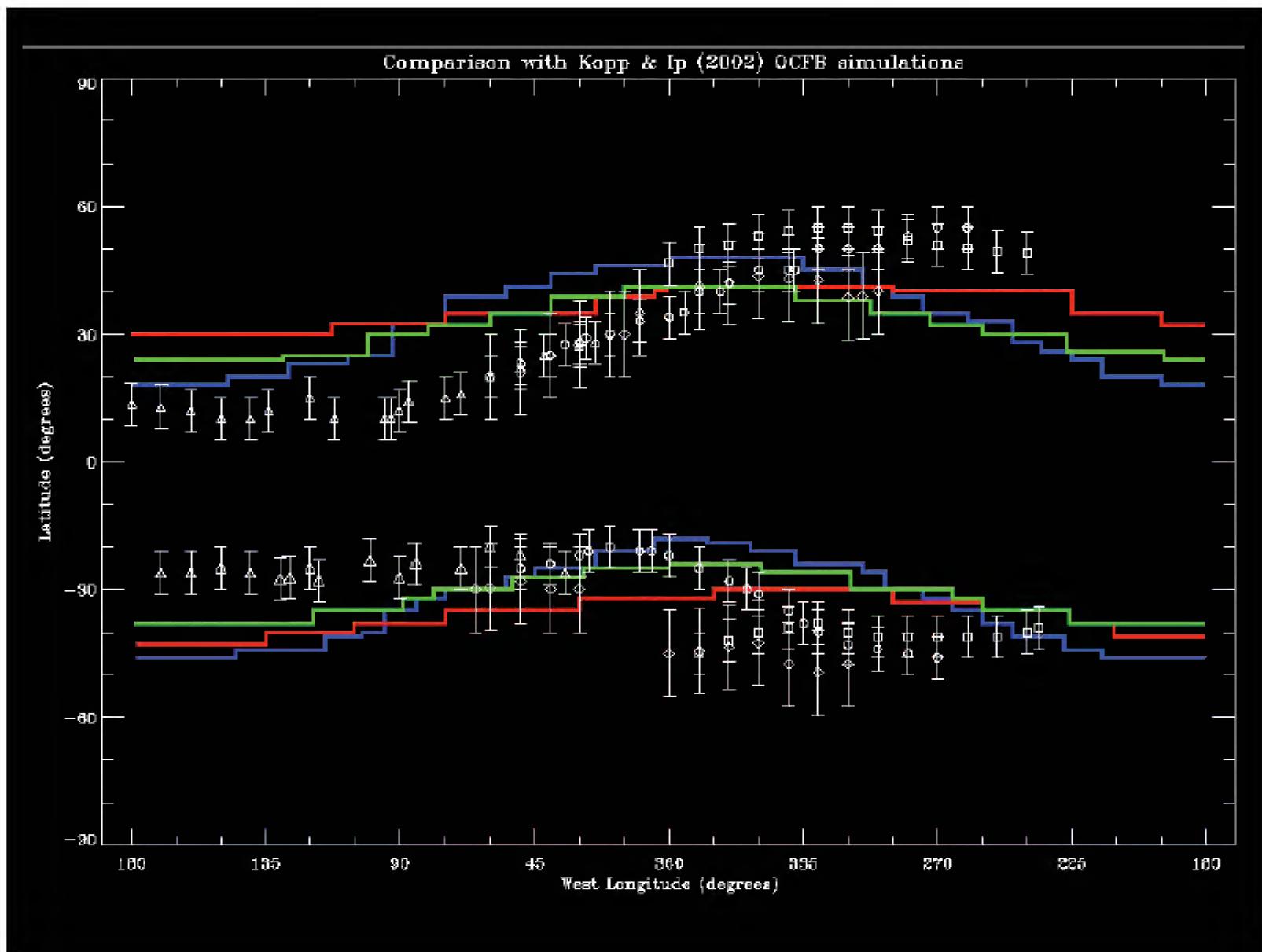


- Torus Plasma Flow
- ⇒ Ganymede's Magnetospheric Flow
- Upstream Reconnection Line
- ▨ Downstream Reconnection Line

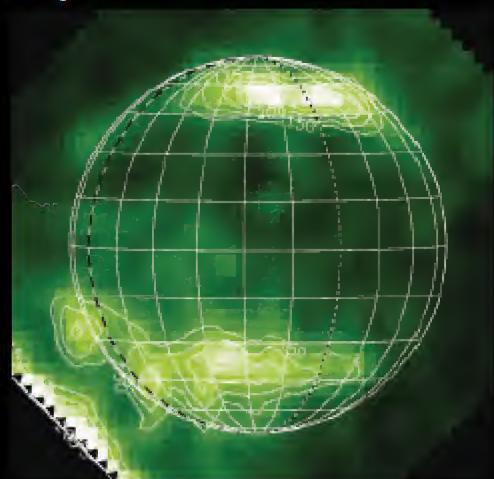
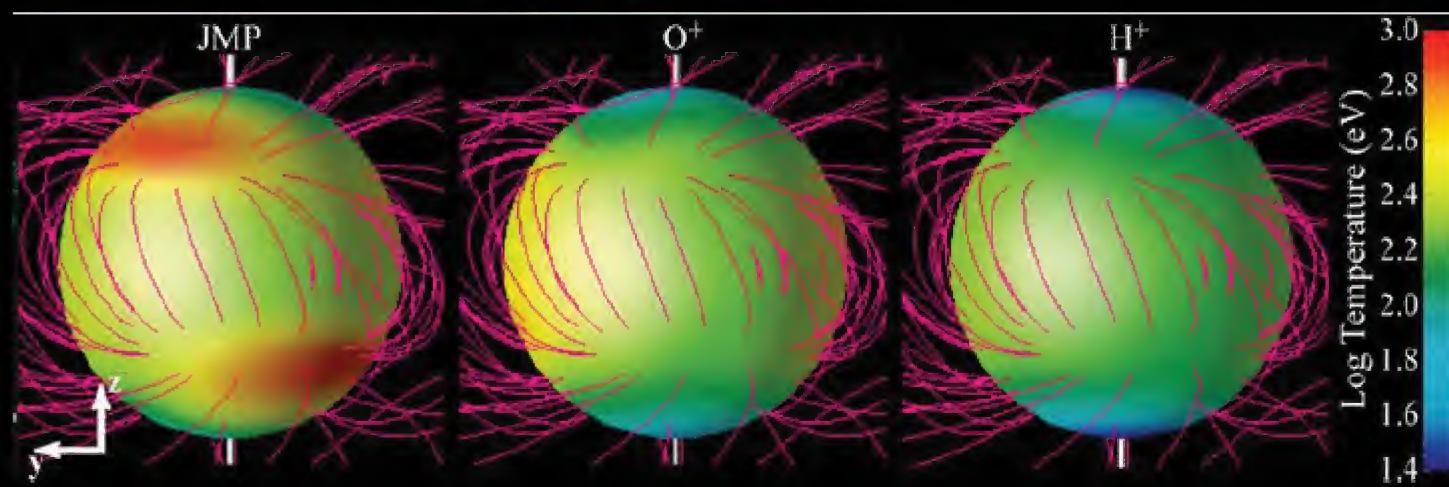
open-closed boundary

Kivelson 2001

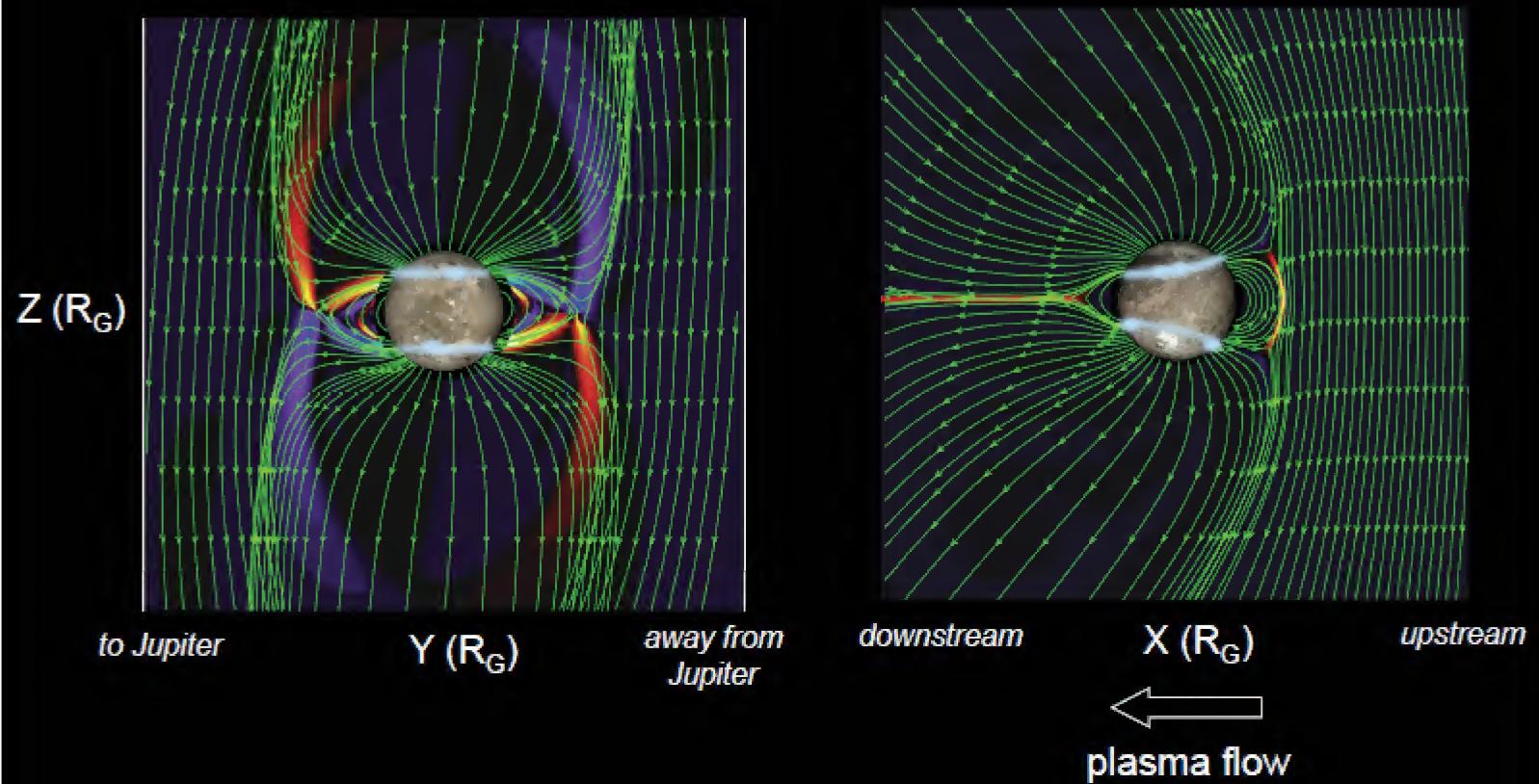




Paty and Winglee (2004)

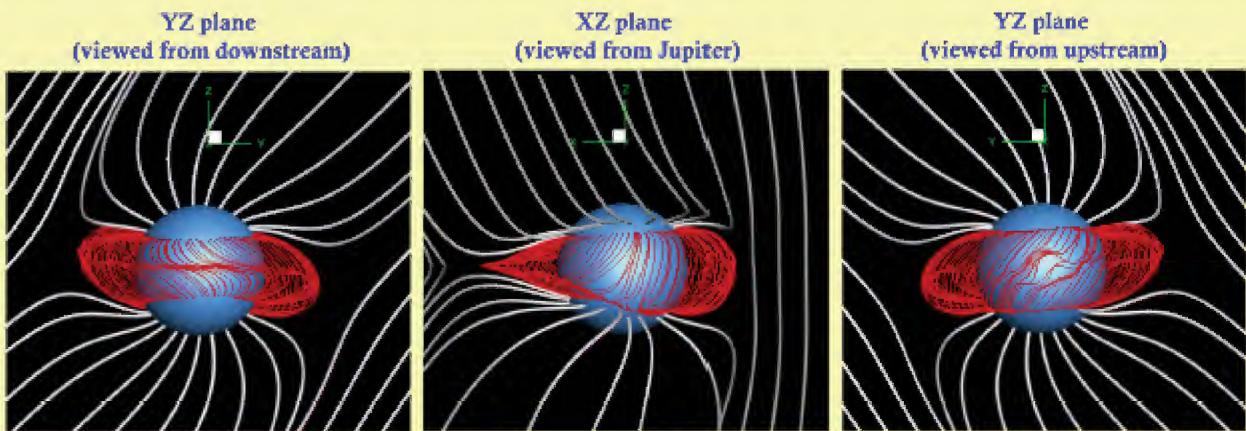


Jia et al. 2008, 2009

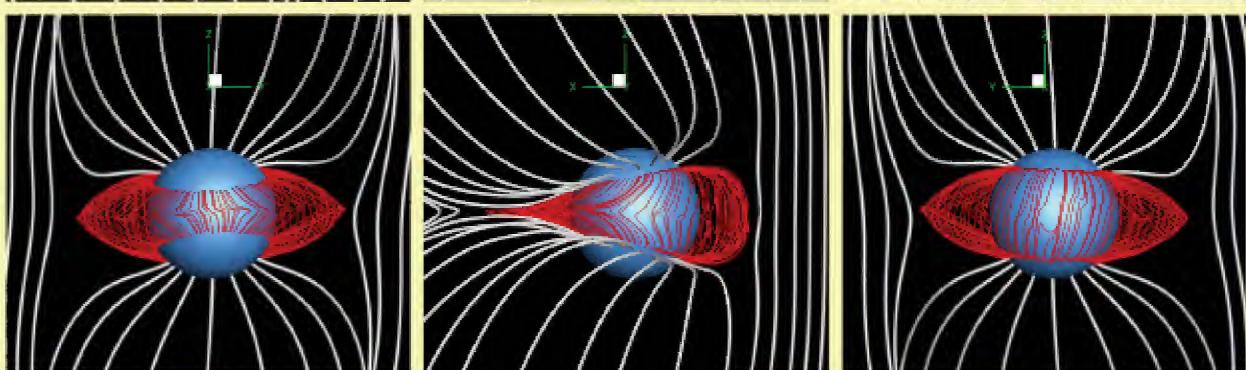


*Jia et al. 2008,
2009*

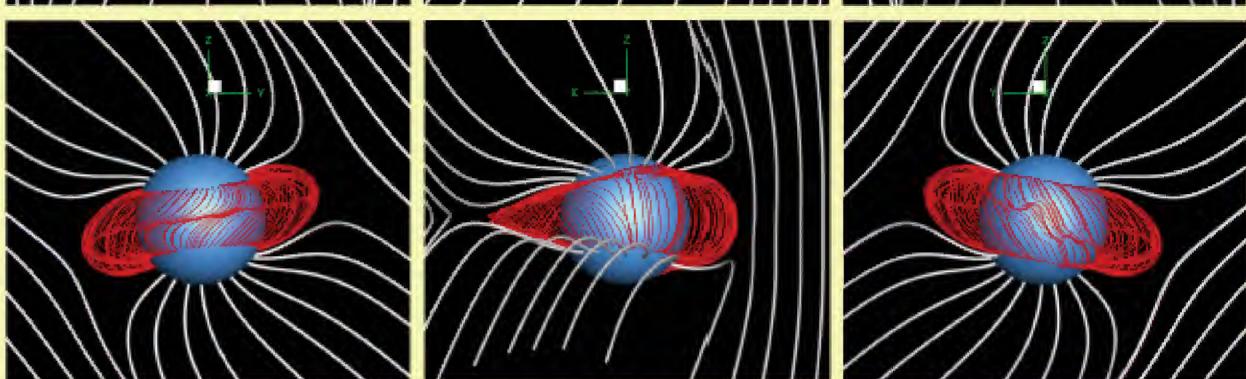
Ganymede is ABOVE
the central current sheet

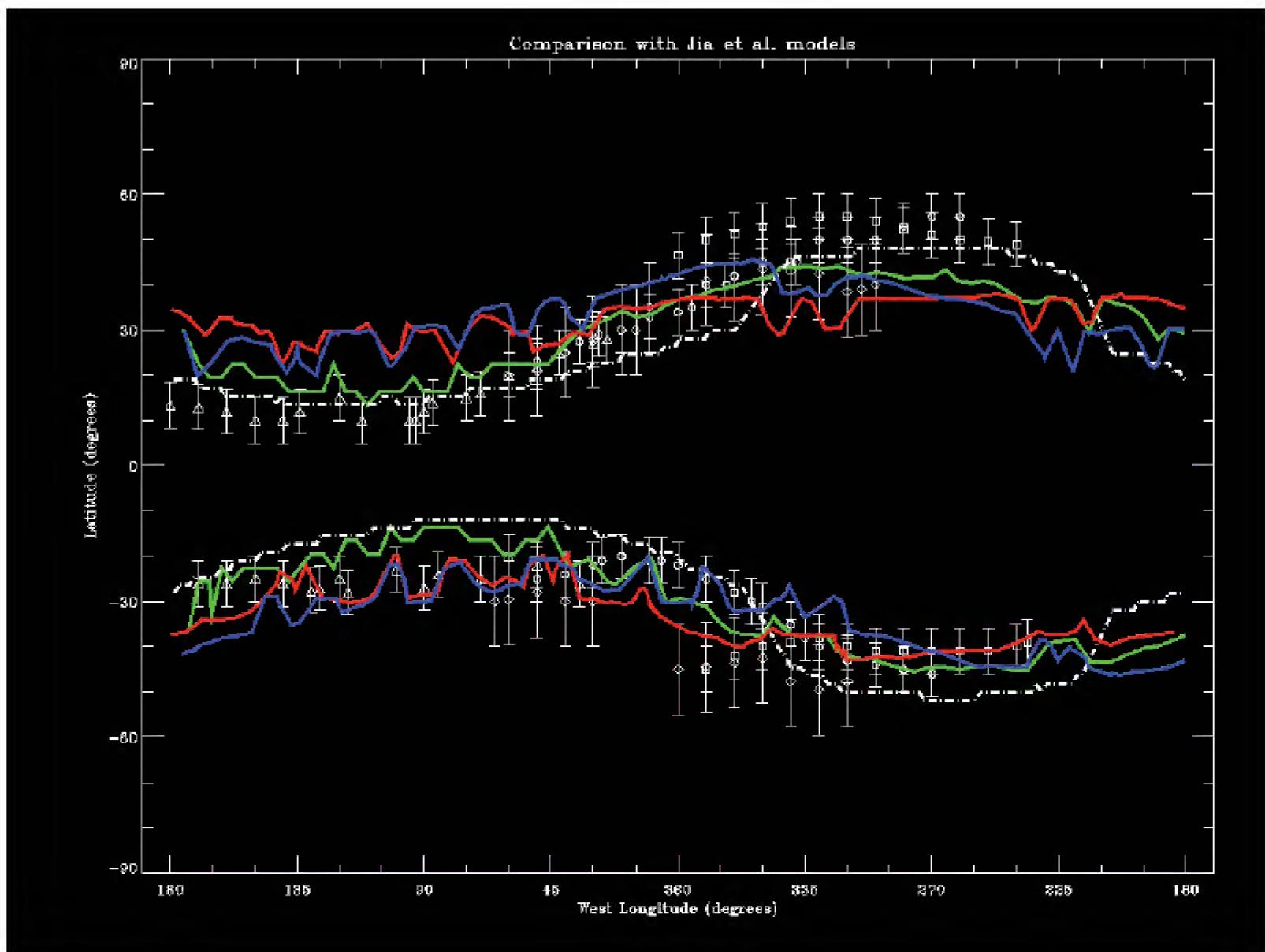


Ganymede is NEAR
the central current sheet

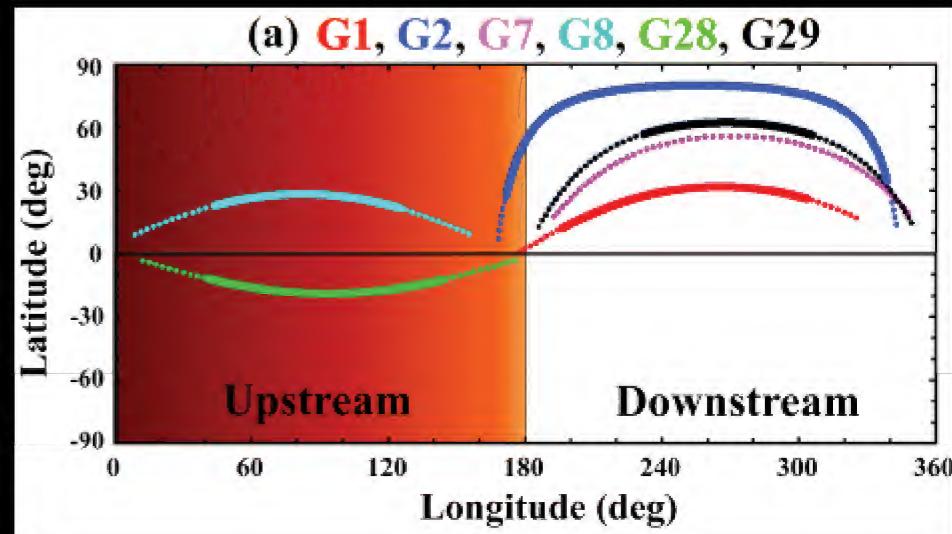


Ganymede is BELOW
the central current sheet

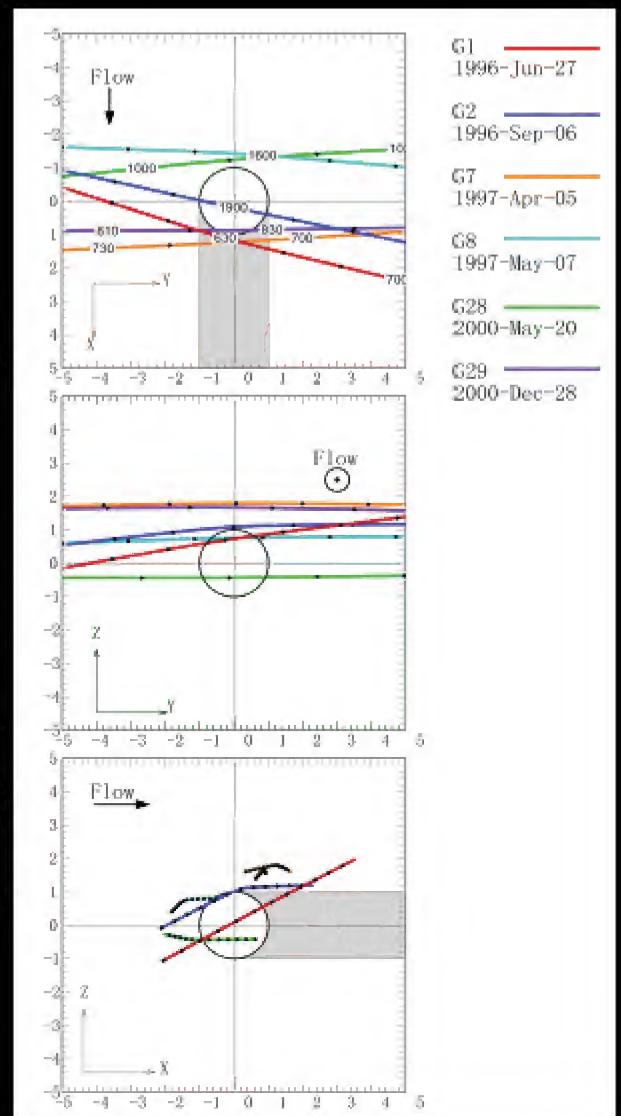




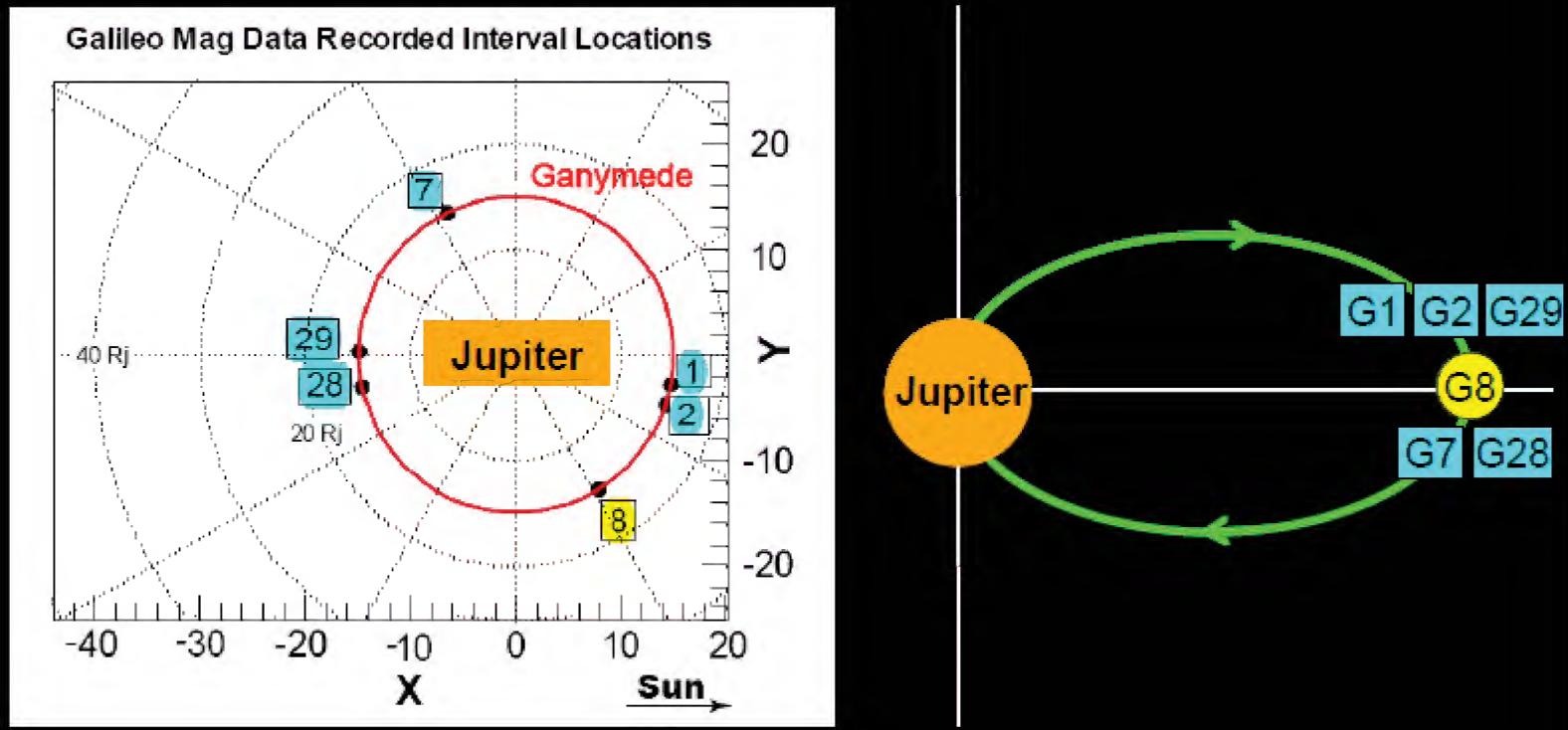
Locations of Galileo's six close encounters with Ganymede



Jia et al. 2009



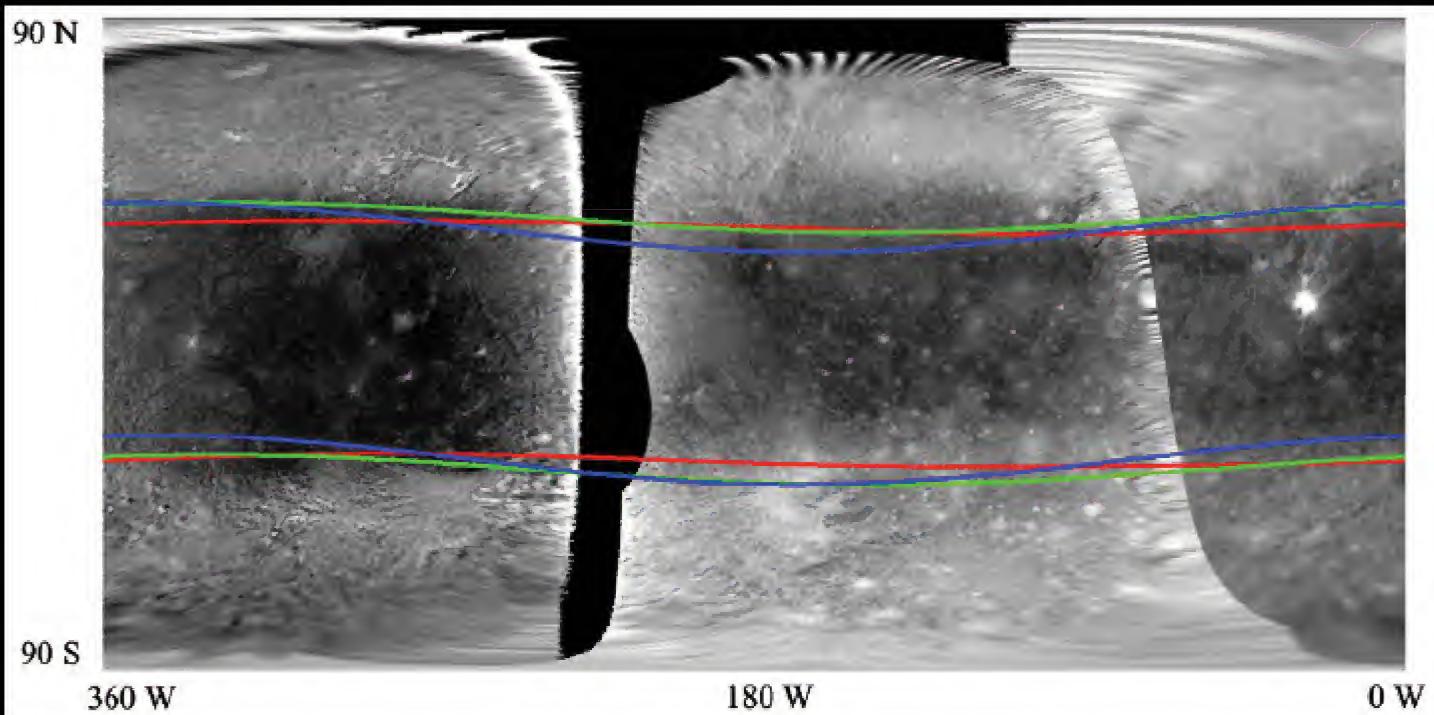
The six close encounters occurred in different local time sectors in Jupiter's magnetosphere and at different locations relative to the Jovian plasma sheet.



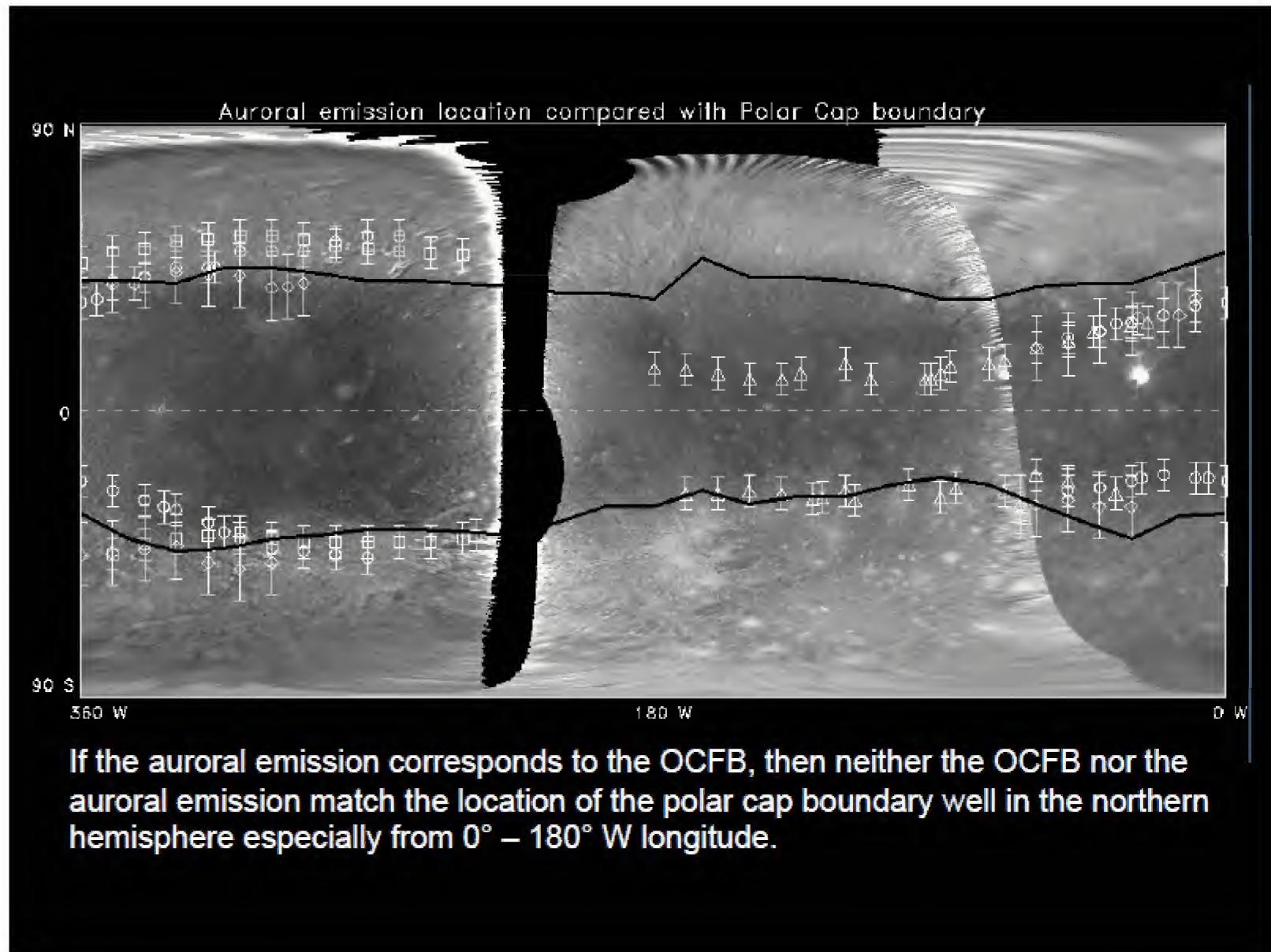
Ganymede has visibly brighter, bluer polar caps



Based on the apparently close correspondence between the OCFB of the Khurana et al. (2009) static superposition model with the polar cap boundary, they concluded that particle bombardment of the poles is the cause of the bright polar caps.

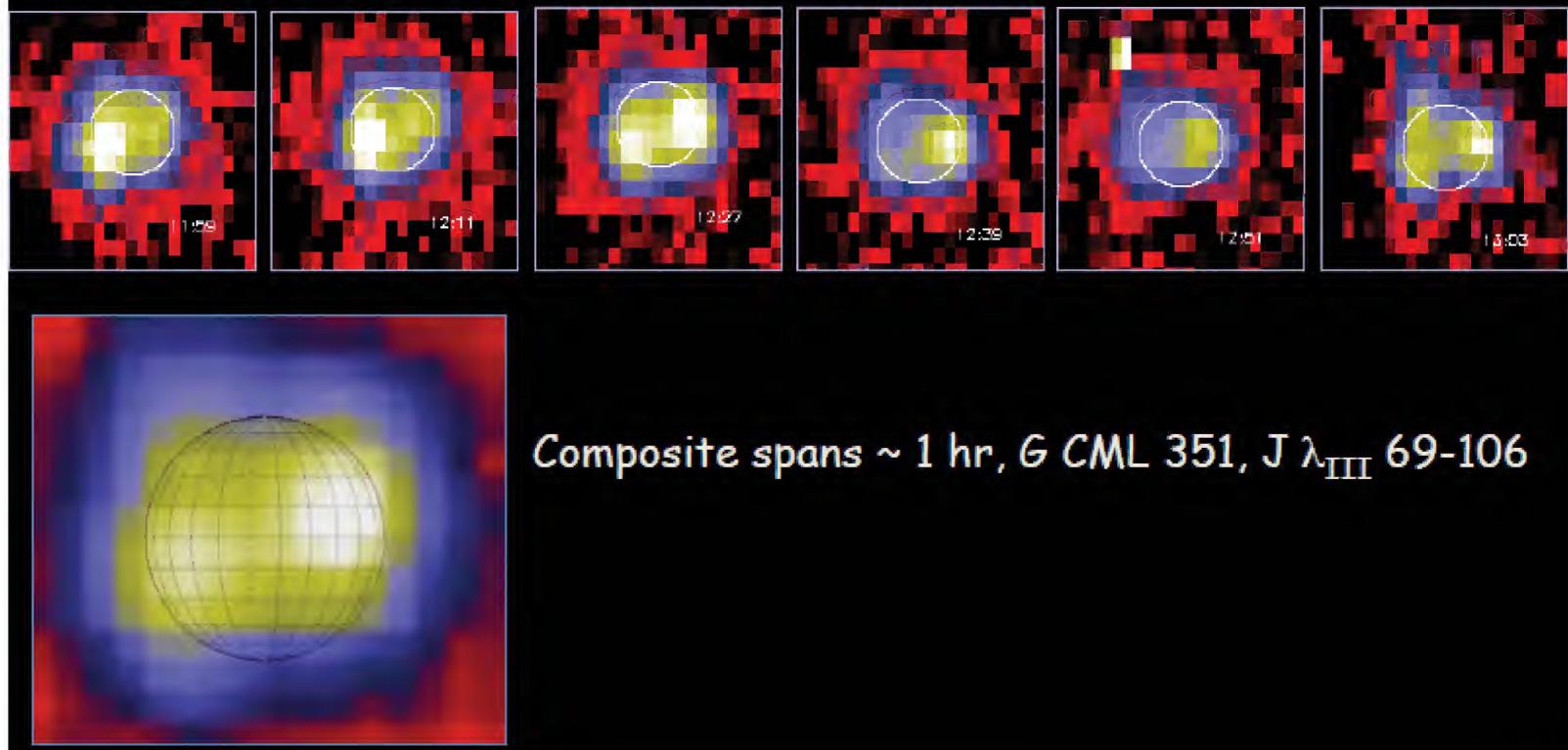


However, I just showed you the close correspondence between the OCFB of the Jia et al. model and auroral emission. Khurana model does not account for the interaction between Jovian plasma and Ganymede.

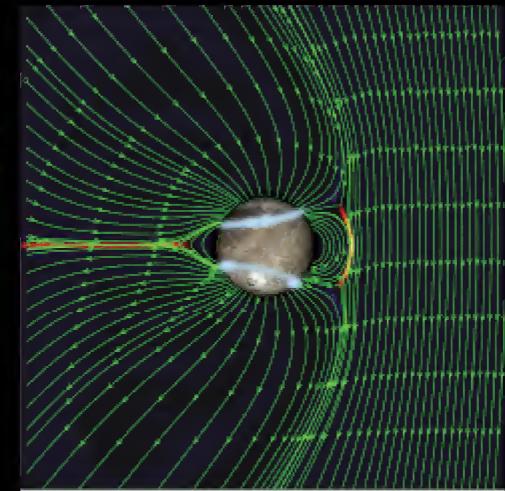
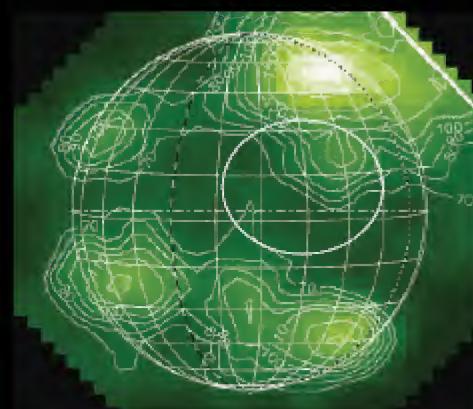
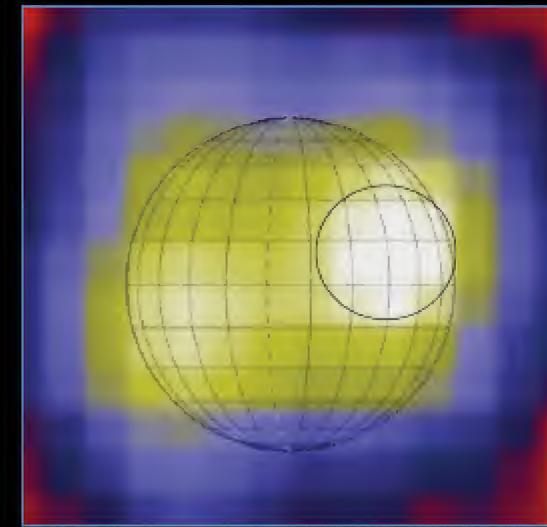


Unpublished Keck observation of Ganymede in eclipse (Jupiter-facing hemisphere - same as 2003 and 2007 UV observations) in oxygen 630 nm emission by Mike Brown:

- visible O emission is not at the poles, it is near the equator
- significant short-term variability



Comparison between visible and UV, almost the same (Jupiter-facing) hemisphere:



Jupiter facing hemisphere, plasma flow from right to left

Summary

- Ganymede has a stable, well-defined pattern of auroral emission: higher latitude on the upstream hemisphere, lower latitude on the downstream hemisphere. The northern oval is bigger than the southern oval.
- The emission pattern is reasonably well matched by the OCFB in the MHD models of Jia et al.
- Puzzling emission morphology has been observed in visible aurora that is inconsistent with the UV morphology.

